DOCTOR
OF
PHILOSOPHY

A THREE-DIMENSIONAL FLUTTER THEORY FOR ROTOR BLADES WITH TRAILING-EDGE FLAPS

Mark A. Couch-Commander, United States Navy
B.S., Purdue University, 1984
M.S., Naval Postgraduate School, 1993
Doctor of Philosophy in Aeronautical and Astronautical Engineering-June 2003
Dissertation Supervisor: E. Roberts Wood, Department of Aeronautics and Astronautics

This dissertation develops the equations of motion for the structural and aerodynamic forces and moments of a rotor blade with a trailing-edge flap using eight degrees of freedom. Lagrange's equation is applied using normal modes to find the flutter frequency and speed similar to the classic fixed-wing method developed by Smilg and Wasserman. However, rotary-wing concerns are addressed, including different freestream velocities along the blade (variation of reduced frequency along the span of the rotor blade) and the influence of previously shed vortices on the aerodynamic forces and moments (Loewy's returning wake). While Loewy did not explicitly state that his 2-D theory would apply to rotor blades with trailing-edge flaps, the manner in which the theory was developed allows it to be applied in this manner. Comparisons to classic 1DOF, 2DOF and 3DOF flutter theories are made to validate this theory in the limiting cases. Flutter analyses, including g-Ω plots, of an example rotor blade with five degrees of freedom are performed for various rigid body flap frequencies.

Classic methods of rotor blade design of ensuring freedom from flutter are to collocate the center of gravity (c.g.), elastic axis (e.a.), and aerodynamic center (a.c) at the 25% chord. With the development of rotor blades with trailing-edge flaps, it is shown that this current design practice is not valid when a trailing-edge flap is incorporated.

KEYWORDS: Flutter, Rotary Wing, Aeroelasticity, Trailing-edge Flaps, Unsteady Aerodynamics, Structural Dynamics, Holzer Method, Myklestad-Prohl Method, Rotor Blades, Vibrations

NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE PERFORMANCE OF STAGGERED SHORT PIN-FIN HEAT EXCHANGERS

Leonard J. Hamilton-Commander, United States Navy
B.S., United States Naval Academy, 1984
M.S., University of Maryland, 1984
Doctor of Philosophy in Mechanical Engineering-June 2003
Advisor: Ashok Gopinath, Department of Mechanical Engineering
Committee Members: Garth V. Hobson, Department of Aeronautics and Astronautics
Terry R. McNelley, Department of Mechanical Engineering
Knox T. Millsaps, Department of Mechanical Engineering
Raymond P. Shreeve, Department of Aeronautics and Astronautics

A three-dimensional finite element based numerical model was used to analyze the heat transfer characteristics of various staggered short pin-fin array heat exchangers. The simulation was validated against data from an experimental rig as well as historical data, and then used to estimate the heat transfer coefficient and pressure drop for a wide range of Reynolds numbers for circular and airfoil-shaped pin fins. Circular pin configuration variations included changes in pin spacing, axial pitch and pin height ratio. Airfoil pin variations also included changes in length and aspect ratio. Correlations for Nusselt number and friction factor were developed. Using established performance metrics, optimum configurations for both

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pin shapes were determined. The optimum airfoil pin array was shown to match the heat transfer rates obtained by the optimum circular pin configuration while incurring less than one third the specific fluid friction power loss. The results from this study would be of direct value in the design of a shroud enclosed heat exchanger concept being proposed for turbine blade cooling, or for cooling of high power electronic components, or in other high heat flux dissipation applications requiring a low-profile, high area-density based micro-heat exchanger design.

KEYWORDS: Numerical Analysis, Heat Transfer, Pin-Fin Heat Exchanger, Turbine Blade Cooling, Electronic Component Cooling

ACOUSTIC BASED TACTICAL CONTROL OF UNDERWATER VEHICLES

William J. Marr-Commander, United States Navy
B.S., United States Naval Academy, 1981
M.S., Naval Postgraduate School, 1994
Doctor of Philosophy in Mechanical Engineering-June 2003
Dissertation Supervisor: Anthony J. Healey, Department of Mechanical Engineering
Committee Members: Morris Driels, Department of Mechanical Engineering
Fotis Papoulias, Department of Mechanical Engineering
Roberto Cristi, Department of Electrical Engineering
Josh Gordis, Department of Mechanical Engineering

Advances in command and control of Autonomous Underwater Vehicles (AUVs) using acoustic communications are crucial to future Fleet objectives, particularly in Very Shallow Water Mine Countermeasures (VSW MCM). Understanding of the capability to redirect missions, provide relatively high rate downloads of mission information, and perform cooperative tracking for multi-vehicle systems is currently limited to some bounding data based on fixed node experiments, while the impact of working in the environment presented by a moving vehicle is not understood.

The main objectives of this dissertation were to investigate and demonstrate the capabilities of tactical acoustic control of a dynamic, operational underwater vehicle in the Very Shallow Water (VSW) ocean environment. This necessarily required studies on the limitations of Acoustic Control and relatively High Data Rate Transfer when using commercial acoustic modems in underwater vehicles, and an investigation of their acoustic transmission characteristics. Comprehensive empirical evidence through field validation with the *ARIES* vehicle indicated that reduced ranges were required for successful acoustic communications in a realistic very shallow water environment. Background noise, multipath reflections, and vehicle induced Doppler shifts all limit the communication link. Occasionally, configurations may be found where vehicle body shielding against multipath destructive interference can be used to advantage. A simulation was developed to demonstrate a solution for reducing the range and conducting multi-vehicle behaviors for cooperative tracking and acoustic communications data transfer.

KEYWORDS: Autonomous Underwater Vehicles, Acoustics, Acoustic Control, Acoustic Data Transfer, Modems

DOCTOR OF PHILOSOPHY

HOLISTIC FRAMEWORK FOR ESTABLISHING INTEROPERABILITY OF HETEROGENEOUS SOFTWARE DEVELOPMENT TOOLS

Joseph F. Puett, III-Lieutenant Colonel, United States Army
B.S., United States Military Academy, 1982
M.S., California Institute of Technology, 1992
M.B.A., Long Island University, 1994
Doctor of Philosophy in Software Engineering-June 2003
Supervisor: Luqi, Department of Computer Science
Advisors: James Bret Michael, Department of Computer Science
Craig W. Rasmussen, Department of Applied Mathematics
Man-Tak Shing, Department of Computer Science
Nelson Ludlow, Mobilisa, Incorporated

This dissertation presents a Holistic Framework for Software Engineering (HFSE) that establishes collaborative mechanisms by which existing heterogeneous software development tools and models will interoperate. Past research has been conducted with the aim of developing or improving individual aspects of software development: however, this research focuses on establishing a holistic approach over the entire development effort, where unrealized synergies and dependencies between all of the tools' artifacts can be visualized and leveraged to produce improvements in both process and product. The HFSE is both a conceptual framework and a software engineering process model (with tool support) where the dependencies between software development artifacts are identified, quantified, tracked, and deployed throughout all artifacts via middleware. Central to the approach is the integration of Quality Function Deployment (QFD) into the Relational Hypergraph (RH) Model of Software Evolution. This integration allows for the dependencies between artifacts to be automatically tracked throughout the hypergraph representation of the development effort, thus assisting the software engineer in isolating subgraphs as needed.

KEYWORDS: Software Evolution, Interoperability, Integrated Software Development Environments, Heterogeneous Software Systems, Quality Function Deployment

EXPERIMENTAL IMPLEMENTATION OF A SINGLE ELEMENT TIME REVERSED ACOUSTIC PULSE (TRAP) SONAR

Mitchell N. Shipley-Commander, United States Navy (Ret.)
B.S., United States Naval Academy, 1979
M.S., Naval Postgraduate School, 1992
Doctor of Philosophy in Engineering Acoustics-June 2003
Supervisor: Andrés Larraza, Department of Physics

The acoustic propagation complexity and variability of the littoral regions provide an increasingly challenging environment in which to conduct submarine sonar detection. Recent research with Time Reversal Acoustics (TRA) has demonstrated the ability of this approach to adapt in real time to these complex environments with little knowledge of the environmental parameters. Experimental active sonar research at the Naval Postgraduate School's Advanced Acoustic Research Laboratory (AARL) uses a laboratory scale, single element, shallow water active sonar system to demonstrate the improvement of target echo signal to noise ratio (SNR) by adapting the sonar transmit pulse in real time to the existing environment. The approach, called Time Reversed Acoustic Pulse (TRAP) sonar, demonstrated a 3 to 7dB SNR gain over more traditional matched filtered active sonar techniques. The SNR gain was demonstrated to be robust even in high noise environments, providing a 5 dB SNR final detection statistic from cases where traditional matched filtered technique had negative SNRs. TRAP sonar system applications for a barrier concept and a variable range focusing technique are also presented.

KEYWORDS: Time Reverse Acoustics, Active Sonar, Signal-to-Noise Ratio, SNR, Waveguide

APPLICATION OF HIGDON NON-REFLECTING BOUNDARY CONDITIONS TO SHALLOW WATER MODELS

Vincent J. van Joolen-Commander, United States Navy
B.S., University of California-San Diego, 1983
M.S., Naval Postgraduate School, 1991
M.S., Army War College, 2000
Doctor of Philosophy in Applied Mathematics-June 2003
Supervisors: Beny Neta, Department of Applied Mathematics
Dan Givoli, Technion, Israel
Committee Members: Clyde Scandrett, Department of Applied Mathematics
Arthur Schoenstadt, Department of Applied Mathematics
Robert Haney, Department of Meteorology

In many applications involving wave propagation, problem domains are often very large or unbounded. A common numerical method used to solve such problems is to truncate the domain via artificial boundaries to form a finite computational domain. To accomplish this, Non-Reflecting Boundary Conditions (NRBCs) which minimize spurious wave reflections are imposed. The quality of the solution strongly depends on the properties of both the NRBC and the wave behavior.

This dissertation explores the use of Higdon NRBCs to solve shallow water equations (SWEs) in a dispersive environment. A linearized SWE model is developed that includes stratification and advection effects. Initially, a single NRBC is used to truncate a semi-infinite channel. Later, four NRBCs are used to restrict an infinite plane. In both cases, finite rectangular domains are formed. A scheme developed by Neta and Givoli is used to rapidly discretize high-order Higdon NRBCs. Finite difference methods are used in all numerical schemes, which are solved explicitly when possible. Results will show that Higdon NRBCs can be used effectively to restrict large rectangular domains when solving SWEs that include the before mentioned effects.

KEYWORDS: Waves, High-order, Artificial Boundary, Non-Reflecting Boundary Condition, Higdon, Finite Difference, Shallow Water Equation, Stratification

ANALYTIC EXPRESSION OF THE BUCKLING LOADS FOR STIFFENED PLATES WITH BULB-FLAT FLANGES

Archie Wilmer, III-Lieutenant Colonel, United States Army
B.S., United States Military Academy, 1982
M.S., Naval Postgraduate School, 1994
Doctor of Philosophy in Applied Mathematics-June 2003
Advisor: Don Danielson, Department of Applied Mathematics

The subject of this research is the buckling behavior of a simply supported rectangular plate, with a bulb-flat stiffener attached to one side of the plate. The plate structure is subjected to axial compression that increases to the buckling load. The stiffener cross-section has a thin web and a bulb-flat flange that extends to one side of the web. Results of the investigation include planar property formulas for the asymmetric flange geometry, an analytic expression for the Saint Venant torsional constant of the flange cross-section, and an analytic expression for the buckling load corresponding to a tripping mode of the structure. The torsional constant for the bulb-flat stiffener is 15% - 23% higher than understood previously. The analytic expression for the buckling load of the bulb-flat stiffened plates considered in this investigation yields values that are 2% - 6% higher than finite element results. It is also shown that the buckling load of a plate with a bulb-flat stiffener is 3% - 4% less than that of a plate with a T-flange stiffener with the same cross-sectional area. At the onset of stiffener tripping, the torsionally superior bulb-flat tends to bend laterally, while the flexurally superior T-flange tends to twist.

KEYWORDS: Stiffened Plates, Bulb-flat, Torsion, Saint Venant, Buckling Load